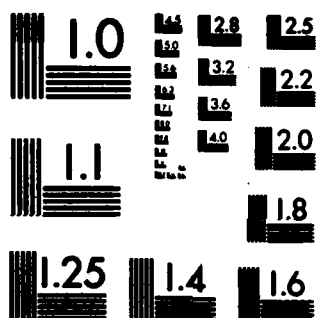END
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ELASTIC COMPLIANCE AND STRESS INTENSITY FACTOR
SOLUTIONS FOR COMPACT SPECIMEN GEOMETRIES

V. Papaspyropoulos
and
J. Ahmad

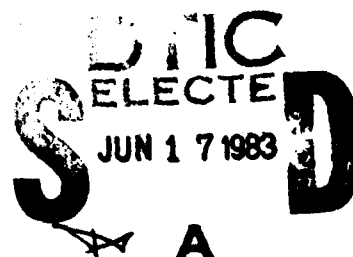
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Two-dimensional linear elastic finite element analyses of several compact tension test specimen geometries were performed. Eight noded isoparametric and singular stress triangular quarter-point elements were used. The results include stress intensity factors and compliance at selected locations as functions of crack length.

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FOREWORD

This report was prepared by the Stress Analysis and Fracture Section, Battelle Columbus Laboratories, Columbus, Ohio, under Project No. 2307, Task No. 2307P1, Work Unit 2307P102, and supported, in part, under Contract F33615-79-C-5129 with Universal Energy Systems, Dayton, Ohio. The research reported here was conducted by V. Papaspyropoulos and Jalees Ahmad.

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FOREWORD

INTRODUCTION

Stress intensity factor (K) solutions for statically loaded standard compact tension (CT) and modified compact tension or wedge-opening load (WOL) specimens are readily available in the open literature. The dimensional parameters of these two test specimen geometries are shown in Figure 1.

For certain special purpose laboratory experiments, it is sometimes desirable to use test specimens which may deviate from standard geometries - such as using a larger than standard W (Figure 1) to allow longer crack growth data. For such cases, K solutions are difficult to find.

Another piece of information which is difficult to find in the literature is the specimen's elastic compliance at experimentally measurable locations. This true for standard as well as non-standard test specimen geometries. Although not nearly as useful a quantity as K for actual structural applications, compliance is an extremely useful quantity for laboratory work. Defined as the displacement at a particular location in the specimen per unit applied load, compliance is a directly measurable quantity. For linear elastic material behavior, compliance is a unique function of crack length for a given geometry - providing a useful method of infering crack lengths from displacement measurements. Also, using the functional relationship and measurements of load-line displacements, K can be evaluated using the following simple relationship

$$K^2 = 1/2 \ E \ \frac{P^2}{B} \frac{\partial \bar{c}}{\partial a} \tag{1}$$

where P is the load, E is the elastic modulus, B is the out-of-plane thickness of the specimen, a is the crack length, and $\bar{c}$ is the load-line compliance.

Other possible uses of compliance are in the evaluation of crack closure and fatigue-crack growth retardation phenomena, automatic crack growth and K monitoring techniques, assessing local plasticity and creep effects, etc.

FIGURE 1. COMPACT SPECIMEN GEOMETRY.

Standard WOL – H/W = 0.486
Standard CTS – H/W = 0.6
Modified CTS – H/W < 0.6

This report contains the results of a series of finite element analyses performed on compact specimen geometries with H/W (see Figure 1) ranging between 0.3 and 0.6. The results are presented in tabular form to avoid inaccuracies associated with reading numbers from graphs. For the cases of standard CT specimen and the WOL specimen, however, plotted results are compared with available analytical and experimental results from the literature.

Method of Solution

A typical finite element mesh used in the analyses is shown in Figure 2. To take advantage of symmetrical loading and the symmetry of the specimen needed to be analyzed. Analyses were performed using a two-dimensional finite element code (see Reference [1] and [2]) employing four singular quarter-point triangular elements around the crack tip and eight node isoparametric elements in the remainder of the domain. The quarter-point elements were evenly spaced with 45 degrees subtended angle at the crack tip and a radial dimension of one fiftieth the crack length A. For all cases the stress intensity factor was computed using the vertical displacement V (normal to the crack line) on the crack surface at a distance r = A/50 behind the crack tip. The relationship between V and K is given as:

$$K = \frac{VG}{2(1 - k)} \sqrt{\frac{2\pi}{r}} \tag{2}$$

where G = shear modulus

ν = Poisson's Ratio (=0.3)

and $\quad k = \nu/(\nu+1)$ (Plane Stress)

$\quad = \nu \qquad$ (Plane Strain)

In all cases except one in which a sinusoidal load was applied to simulate the contact force between load-pin and the specimen, a concentrated force was applied at point p (Figure 1).
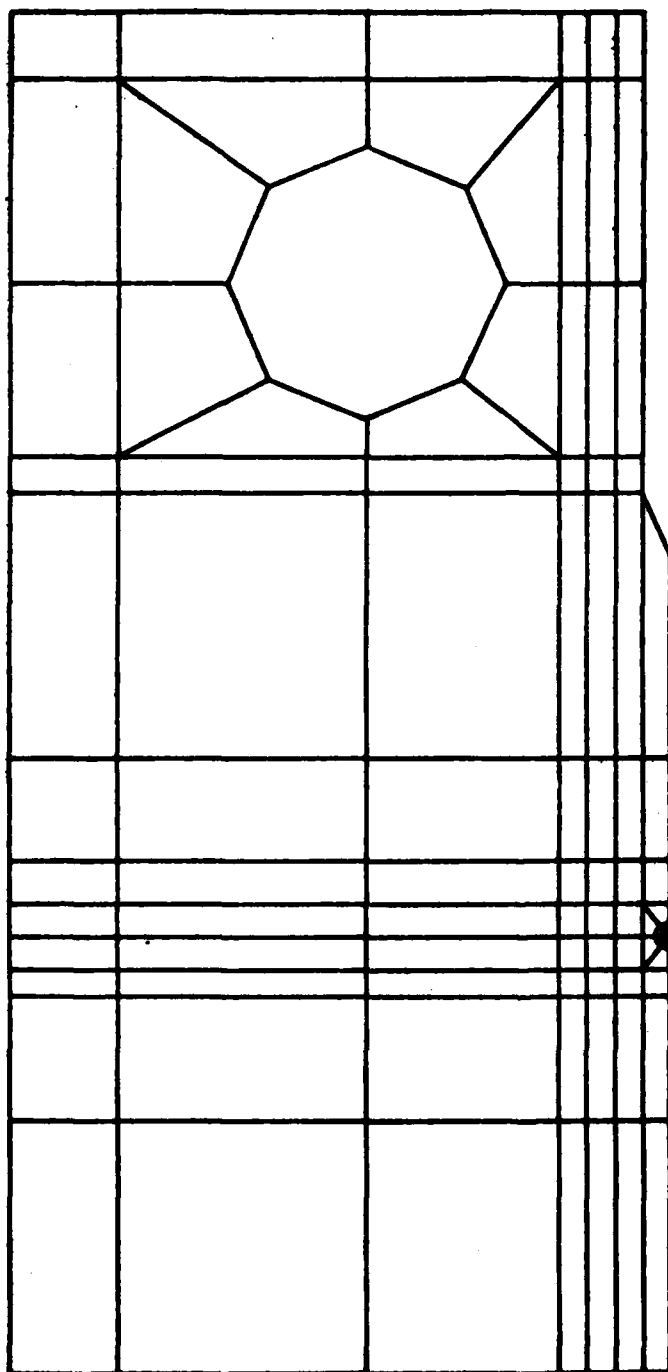
FIGURE 2. TYPICAL FINITE ELEMENT MESH.

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Crack-opening displacements (COD) were recorded at points m and ℓ and load-line displacements (δ_{LL}) were recorded at points p and g (Figure 1). These displacements were then used to find the non-dimensional compliance values using the following relationships:

$$C = EB \frac{(COD)}{P}$$ (3)

and

$$\delta = EB \frac{(\delta_{LL})}{P}$$ (4)

where, P is the applied load.

Non-dimensional stress intensity factor was found by using the following relationship:

$$Y = \frac{KB\sqrt{W}}{P}$$ (5)

In the finite element solution for displacements, a state of plane stress was assumed. Accordingly, all the compliance values are for plane-stress condition. To obtain plane strain compliance values, the reported values should be multiplied by $(1 - \nu^2)$, where ν is the Poisson's ratio.

Results and Discussion

For the WOL specimen, reliable experimental values of crack opening compliance* as well as analytical solution for K were found in the literature (References [3] and [4]). A direct comparison of the present results with the reference values was therefore possible. This is shown in Figure 3. The results of the present analyses are also contained in Table 1.

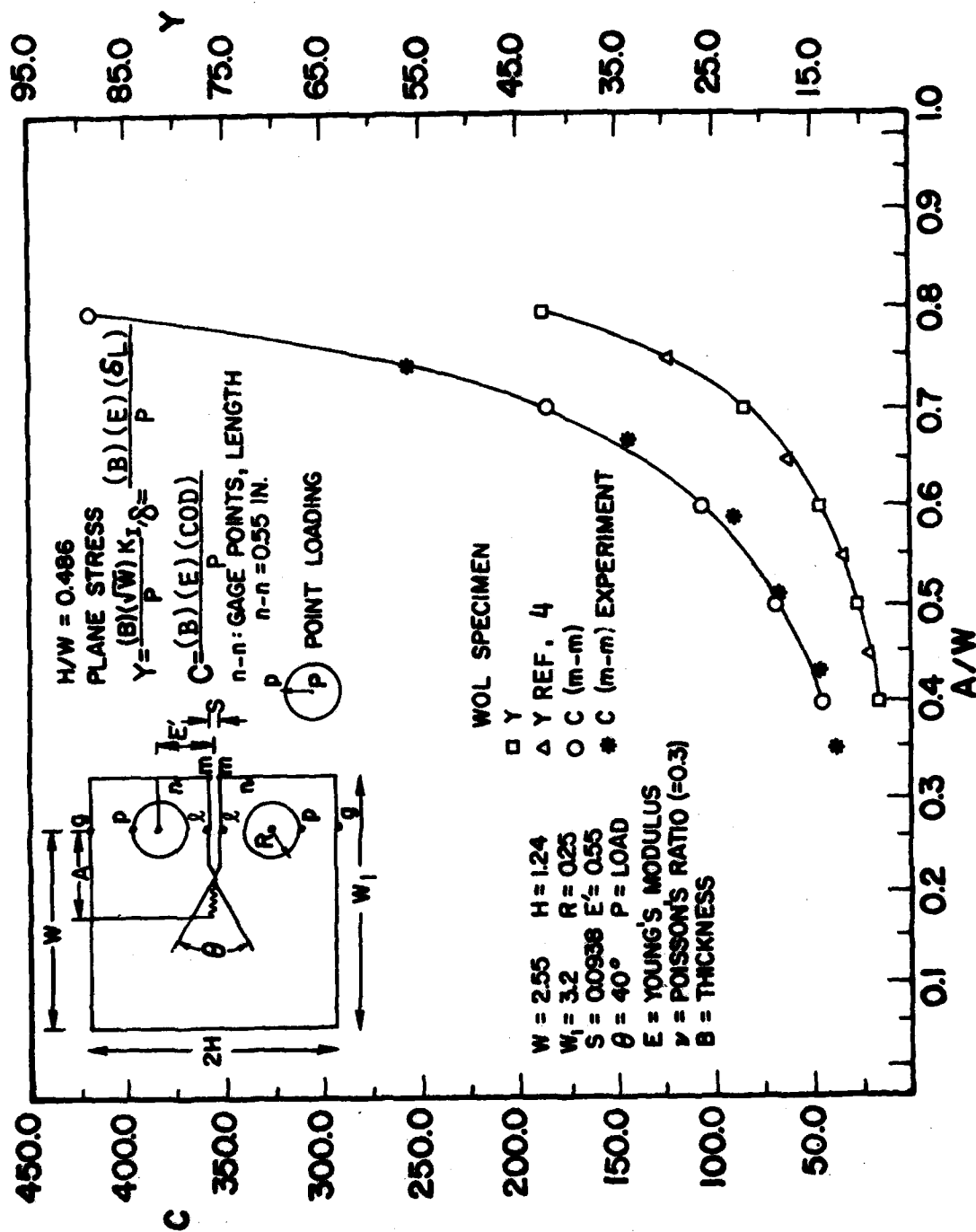*These values were obtained using raw data not reported explicitly in (Reference [3].

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FIGURE 3. COMPARISON OF RESULTS FOR H/W = 0.486.

TABLE 1. THE WOL SPECIMEN (H/W = 0.486)

A/W	Y	C (m-m)	C (ℓ-ℓ)	$\frac{\delta}{2}$ (p-p)	$\frac{\delta}{2}$ (g-g)
0.35	7.4653	38.5566	23.4172	14.30884	12.96862
0.4	8.1265	44.25632	27.9493	16.53571	15.17502
0.5	10.3311	67.1919	45.11700	25.02486	23.66484
0.509	10.7742	73.61198	49.3477	27.29817	25.95528
0.6	14.1225	105.15126	74.0288	39.50525	38.1442
0.7	21.9323	184.3378	135.2912	70.15431	68.79270
0.8	42.1373	417.0342	317.2428	161.14040	159.7786
0.85	68.01935	772.2640	595.8116	300.5822	299.2377
0.9	84.3937	1837.7638	1437.2062	721.2819	719.9373

Reference analytical solution was found for the standard CT specimen as well [5]. Both K and C values for this geometry are compared with the present solution in Figure 4. To simulate the contact force between the loading pins and the hole, a sinusoidally distributed load was considered. The results (Table 2), however, were not significantly different than those obtained by applying a concentrated load (Table 3). This "rediscovery" of the St. Venant's principle helped in the decision of using only concentrated load for the rest of the cases. The results are given in Tables 4 to 8.
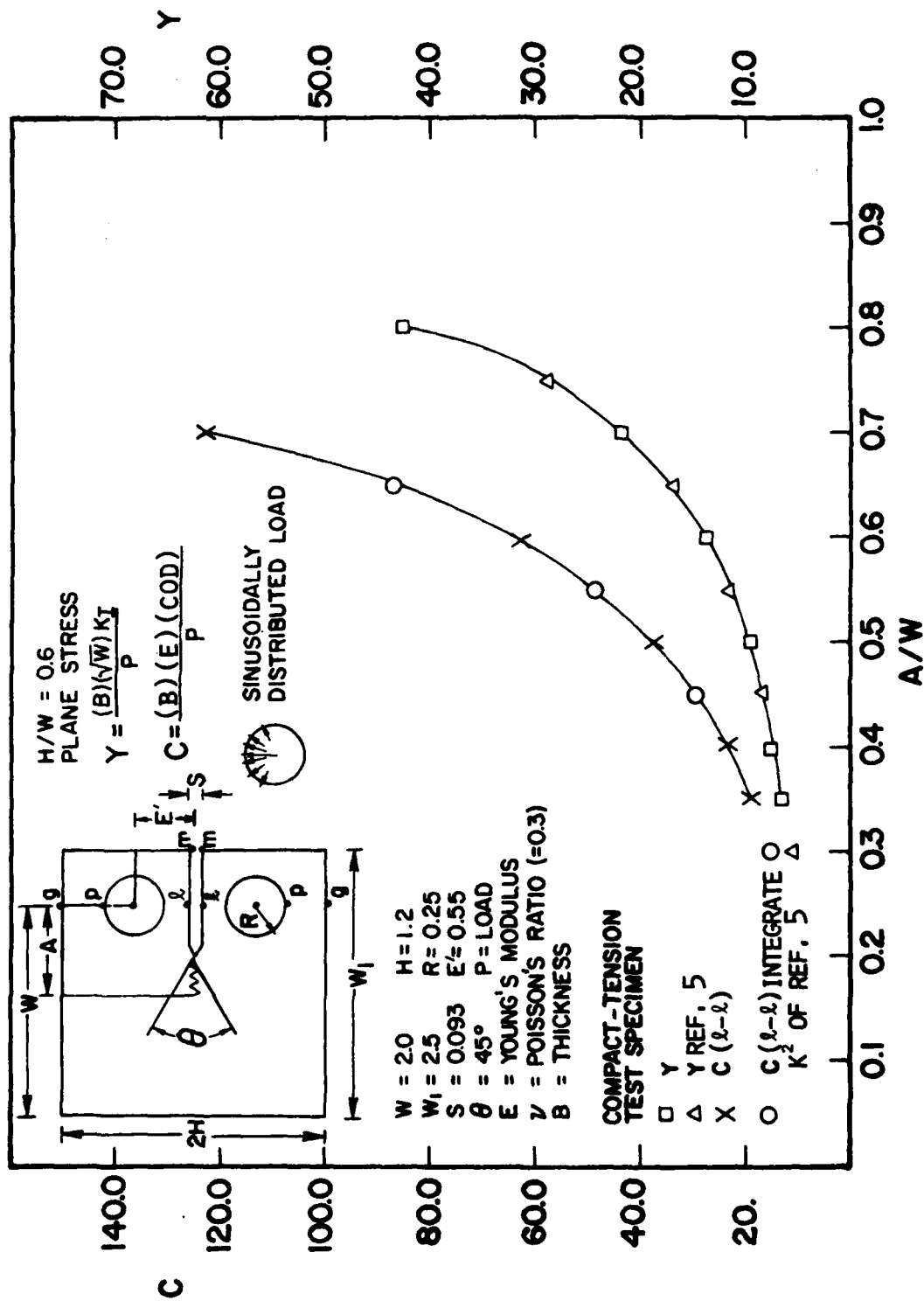
FIGURE 4. COMPARISON OF RESULTS FOR H/W = 0.6.

TABLE 2. THE COMPACT TENSION SPECIMEN (H/W = 0.6) WITH CONCENTRATED PIN-LOAD.

A/W	Y	$\frac{C}{2}$ (m-m)	$\frac{C}{2}$ (ℓ-ℓ)	$\frac{\delta}{2}$ (p-p)	$\frac{\delta}{2}$ (g-g)	Y	$\frac{C}{2}$ (ℓ ℓ)
0.35	6.4046	14.54245	9.215694	10.34275	9.902922	6.39190	9.1376
0.4	7.2675	17.69912	11.60044	12.67651	12.23714	7.27873	11.4689
0.5	9.6407	26.96263	18.63661	19.68247	19.24289	9.65908	18.5423
0.6	13.7119	44.03555	31.76254	32.82077	32.38021	13.6541	31.8094
0.7	21.8700	82.08065	61.35191	62.43501	61.99355	21.5518	61.5715
0.8	42.4768	197.4746	151.9542	153.0611	152.619	41.1998	152.767

TABLE 3. THE COMPACT TENSION SPECIMEN (H/W = 0.6) WITH SINUSOIDALLY DISTRIBUTED PIN-LOAD

A/W	Y	$\frac{C}{2}$ (m-m)	$\frac{C}{2}$ (ℓ-ℓ)	$\frac{\delta}{2}$ (p-p)	$\frac{\delta}{2}$ (g-g)
0.35	6.37451	14.55624	8.891305	11.65514	10.33469
0.4	7.25637	17.70461	11.26977	13.98276	12.66276
0.5	9.64482	26.96656	18.30516	20.98765	19.66750
0.6	13.71740	44.04669	31.43724	34.13143	32.81030
0.7	21.87322	82.09984	61.03389	63.75179	62.42976
0.8	42.47798	197.4998	151.6423	154.3823	153.0596

TABLE 4. H/W = 0.3.

A/W	Y	$\frac{C}{2}$ (m-m)	$\frac{C}{2}$ (ℓ-ℓ)	$\frac{\delta}{2}$ (p-p)	$\frac{\delta}{2}$ (g-g)
0.375	12.23314	41.38094	28.41814	31.07407	29.73008
0.4	12.78784	46.32944	32.28951	34.95315	33.60893
0.45	13.92684	57.41910	41.08556	43.75954	42.41504
0.5	15.14398	70.28960	51.45647	54.13538	52.79078
0.6	18.08192	103.1533	78.46063	81.14051	79.88374
0.7	24.09560	154.5676	121.5215	124.1982	122.8537
0.8	39.70038	270.9966	220.2364	222.9093	221.5649
0.9	116.12902	872.0188	733.5802	736.2503	734.9058

TABLE 5. H/W = 0.35.

A/W	Y	$\frac{C}{2}$ (m-m)	$\frac{C}{2}$ (ℓ-ℓ)	$\frac{\delta}{2}$ (p-p)	$\frac{\delta}{2}$ (g-g)
0.35	9.87764	28.78318	18.7614	21.38464	20.12809
0.4	10.79607	35.69456	24.01575	26.65838	25.31485
0.5	12.94783	53.51369	37.94367	40.61343	39.26903
0.6	16.20869	79.05531	58.46193	61.14131	59.79669
0.7	22.77072	123.4446	94.78495	97.46507	96.12046
0.8	41.43531	237.3453	189.0629	191.7407	190.3962
0.9	123.80808	861.4193	709.4974	712.1740	710.8294

TABLE 6. H/W = 0.4.

A/W	Y	$\frac{C}{2}$ (m-m)	$\frac{C}{2}$ (ℓ-ℓ)	$\frac{\delta}{2}$ (p-p)	$\frac{\delta}{2}$ (g-g)
0.4	9.48575	29.19162	19.05572	21.67686	20.33423
0.5	11.58952	43.44088	29.95362	32.60644	31.26253
0.6	15.07205	65.48670	47.13445	49.80424	48.45972
0.7	22.36473	106.9525	80.20965	82.88683	81.54215
0.8	41.51622	221.1302	172.2971	174.9758	173.6311
0.9	128.56087	868.6010	698.6762	701.3561	700.0114

TABLE 7. H/W = 0.45.

A/W	Y	$\frac{C}{2}$ (m-m)	$\frac{C}{2}$ (ℓ-ℓ)	$\frac{\delta}{2}$ (p-p)	$\frac{\delta}{2}$ (g-g)
0.35	7.76047	20.37055	12.51094	15.11054	13.76991
0.4	8.59826	24.95687	15.86601	18.46967	17.12806
0.5	10.75293	37.23396	25.06362	27.69471	26.35156
0.6	14.41901	57.11458	40.33203	42.98775	41.64372
0.7	22.06794	97.31741	71.72699	74.39738	73.05295
0.8	42.12144	213.2753	163.2706	165.9479	164.6034
0.9	128.96946	873.6962	689.0599	691.7411	690.3965

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TABLE 8. H/W = 0.5.

A/W	Y	$\frac{C}{2}$ (m-m)	$\frac{C}{2}$ (ℓ-ℓ)	$\frac{\delta}{2}$ (p-p)	$\frac{\delta}{2}$ (g-g)
0.35	7.13730	18.15171	10.87623	13.48024	12.14051
0.4	7.98714	22.14034	13.74843	16.34232	15.00174
0.5	10.21446	33.21923	21.88499	24.49351	23.15133
0.6	14.05034	52.14483	36.09857	38.73237	37.38906
0.7	21.92371	92.03404	66.53381	69.18762	67.84365
0.8	42.22624	209.9053	157.4617	160.1279	158.7836
0.9	131.05606	890.5603	687.3347	690.00076	688.6633

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